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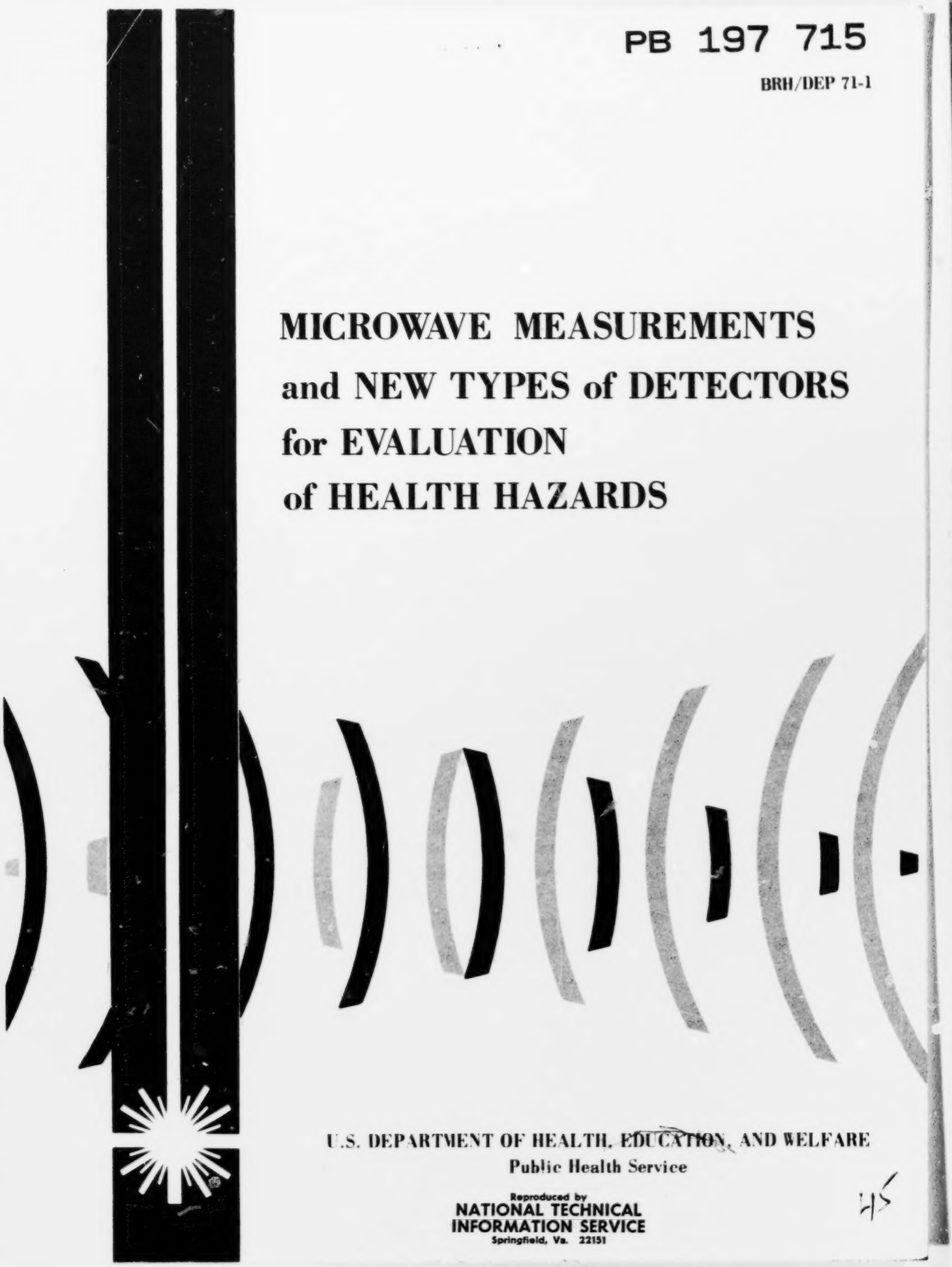
MICROWAVE MEASUREMENTS and NEW TYPES of DETECTORS for EVALUATION of HEALTH HAZARDS



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MICROWAVE MEASUEMENTS and NEW TYPES of DETECTORS for EVALUATION of HEALTH HAZARDS

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Radiation Measurements and Calibration Branch
Divisicn of Electronic Products

January 1971

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Bureau of Radiological Health
Rockville, Maryland 20852

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FOREWORD

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Within the Bureau, the Division of Electronic Products (1) develops and administers performance standards for radiation emissions from electronic products, (2) studies and evaluates emissions of and conditions of exposure to electronic product radiation and intense magnetic fields, (3) conducts or supports research, training, development, and inspections to control and minimize such hazards, and (4) tests and evaluates the effectiveness of procedures and techniques for minimizing such exposures.

The Bureau publishes its findings in Radiological Health Data and Reports (a monthly publication), Public Health Service numbered reports, appropriate scientific journals, and technical report series for the Bureau's divisions, offices, and laboratories.

The technical reports of the Division of Electronic Products (DEP) allow comprehensive and rapid publishing of the results of intramural and contractor projects. The reports are distributed to State and local radiological health program personnel, Bureau technical staff, Bureau advisory committee members, university radiation safety officers, libraries and information services, industry, hospitals, laboratories, schools, the press, and other interested individuals. These reports are also included in the collections of the Library of Congress and the National Technical Information Service.

I encourage the readers of these reports to inform the Bureau of any omissions or errors. Your additional comments or requests for further information are also solicited.

John C. Villforth
Director
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PREFACE

The Division of Electronic Products, Bureau of Radiological Health, as a part of its responsibility under the "Radiation Control for Health and Safety Act of 1968", conducts a program to evaluate the effectiveness of procedures and techniques for minimizing exposure to radiation from electronic products. This report discusses the technical problems associated with the measurement and detection of microwaves for hazard protection. It presents a technical briefing on microwave measurement theory and describes some of the microwave detection instrumentation being used and under development. The descriptions are meant to be general and not inclusive of all available instrumentation.

Robert L. Elder, Sc.D.
Director
Division of Electronic Products

CONTENTS

	Page
FOREWORD	iii
PREFACE	v
FIGURES	viii
ABSTRACT	ix
1. INTRODUCTION	1
2. THEORETICAL DISCUSSION	2
2.1 THE NEAR FIELD	2
2.2 THE EFFECT OF ANTENNA SIZE	6
2.3 ANTENNA IMPEDANCE AND BACKSCATTER	7
2.4 POLARIZATION	13
3. MICROWAVE DETECTORS	14
3.1 TYPES OF DETECTORS	14
3.2 INSTRUMENT RESPONSE TIME	15
3.3 POWER DENSITY INSTRUMENTATION	15
3.4 THE NARDA 8100 - A THERMOCOUPLE DETECTOR	19
3.5 DIODE DETECTOR INSTRUMENTS	21
REFERENCES	33

FIGURES

		Page
Figure 1.	Electric and magnetic fields very near to a dipole . .	1
Figure 2.	Beginning of a far field	6
Figure 3.	Reflection and standing wave creation by presence of large receive antenna	8
Figure 4.	The reflectometer block schematic	10
Figure 5.	Relative reflected power when probes of given wing length are passed along slot at 2 cm above ground plane	11
Figure 6.	Effect of dipole impedance variation on field strength measurements	12
Figure 7.	Fast response of Narda 8100 to stepped RF output, Model 8110-8122 combination	16
Figure 8.	Slow response of Narda 8100 to stepped RF input, Model 8110-8122 combination	17
Figure 9.	Instrument reading as a function of item (fast and slow response): double fan stirrer	18
Figure 10.	The Narda 8100 system	20
Figure 11.	Crossed dipole elements	20
Figure 12.	IITRI instrument	22
Figure 13.	Schematic of IITRI near-field instrument	24
Figure 14.	Schematic of an individual receiving dipole	25
Figure 15.	Energy density meter: antenna and antenna follower circuits	27
Figure 16.	Energy density meter: additional circuitry	28
Figure 17.	Complete power density meter	29
Figure 18.	Basic construction of membrane	29

ABSTRACT

This report discusses the technical problems associated with the measurement and detection of microwaves for hazard protection and describes some of the instrumentation which is being used and developed for that purpose. The problems of measurement in the near field and the interpretation of near-field measurements are reviewed, and instrument design parameters necessary for unambiguous measurements are presented. Emphasis is placed upon the antenna size, direction, and polarization sensitivity. A brief discussion of types of detectors and the response of various instruments is included.

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MICROWAVE MEASUREMENTS AND NEW TYPES OF DETECTORS FOR EVALUATION OF HEALTH HAZARDS

1. INTRODUCTION

The concern over harm to the human body from microwave radiation has created a need for extending the state-of-the-art of electromagnetic field detection and measurement. The need has arisen because of the accessibility to the general public of microwave sources such as microwave ovens, microwave diathermy equipment, radar, and some high powered transmitting antennas. Plane-wave field detection and plane-wave power density measurements are well understood and easily performed with any antenna and receiver calibrated for use in the frequency range of interest. The complexity of measurement in the near field generated by single or multiple microwave sources, however, is not widely understood. Accurate near-field and near-zone measurements are at best difficult to make and require properly designed and used instruments.

In order to understand the complexity of the problem, it is necessary to discuss in some detail the interpretation of near-field measurements as well as the perturbing effects of measuring instruments on the measured field itself.

2. THEORETICAL DISCUSSION

2.1 THE NEAR FIELD

The measurement of the near field can best be understood by considering an example of the generation of electromagnetic radiation. The generation of electromagnetic waves is conceptually not simple. The most simple approach is to consider the case of an electric monopole or dipole antenna in which charge motion occurs along a single axis. The charge distribution and charge motion along a wire generate electric and magnetic fields as shown in figure 1.

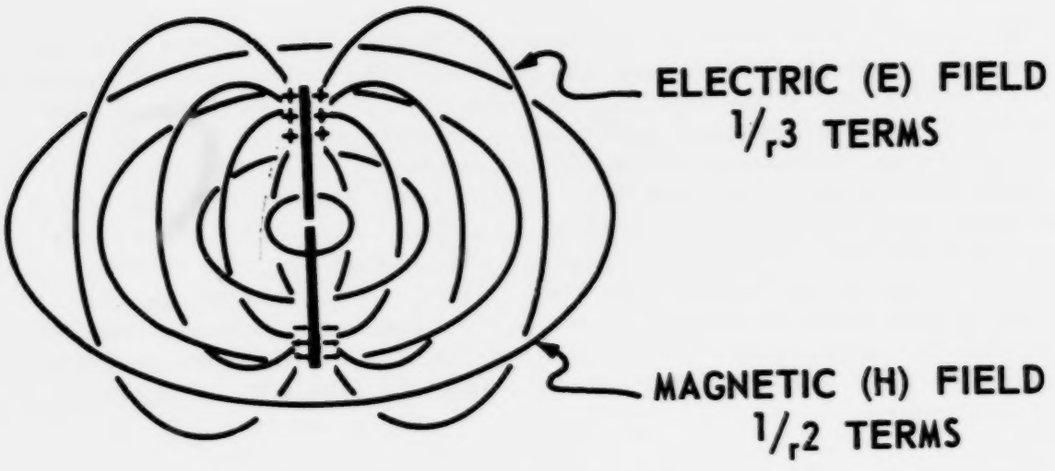


Figure 1. Electric and magnetic fields very near to a dipole.

We recall from basic physics that changing electric fields generate magnetic fields and changing magnetic fields generate electric fields. The illustration of figure 1 would become quite complex if we included these induced fields. The electric and magnetic fields shown and the induced fields can be represented mathematically as follows:

$$E_r = 2A\, Z_o \cos\theta \left[\frac{1}{2\pi}\left(\frac{\lambda}{r}\right)^2 - \frac{j}{(2\pi)^2}\left(\frac{\lambda}{r}\right)^3\right] \qquad (1)$$

$$E_\Theta = A\, Z_o \sin\theta \left[j\left(\frac{\lambda}{r}\right) + \frac{1}{2\pi}\left(\frac{\lambda}{r}\right)^2 - \frac{j}{(2\pi)^2}\left(\frac{\lambda}{r}\right)^3\right] \qquad (2)$$

$$H_\phi = A \sin\theta \left[j\left(\frac{\lambda}{r}\right) + \frac{1}{2\pi}\left(\frac{\lambda}{r}\right)^2\right] \qquad (3)$$

where: $A = I_o\, L\, e^{j\omega(t - \frac{r}{c})}$

$Z = \frac{1}{\varepsilon_o c}$ = impedance of free space

L = length of dipole

I_o = current in antenna

ω = angular frequency

c = velocity of light

λ = wavelength

r = distance from dipole

θ = angle between direction of dipole and direction of vector r

These equations represent the fields generated by a small electric dipole. These equations contain the terms λ/r, λ/r^2, and λ/r^3. Thus, when r is very much smaller than λ, the λ/r^3 term dominates and we refer to this region as the $1/r^3$ region or the near-field region. As λ/r approaches 1, the λ/r^2 and the λ/r terms become more pronounced; this region is called the intermediate field. An analogy can be drawn between the near field (or nonradiating field) and the far fields that were depicted in figure 1. Near fields can be detected and energy can be coupled from the source through them, provided a detector can be placed within a distance of the order of a wavelength away. This is easily accomplished in the microwave region because the distances involved are on the order of centimeters. An article in the March 1970 issue of Scientific American[1] gives a method of detecting these near-field components in the visible region. This, of course, is no simple task since a wavelength in the visible region is about 5000 angstroms or 5×10^{-5} cm. However, it is an exciting result to dramatically see a parallel between visible light and radiowave generation.

As one moves further from the source and r becomes large with respect to λ, the terms in λ/r^2 and λ/r^3 can be neglected, and the term λ/r dominates. Equation (1) in this case can be neglected, and equations (2) and (3) reduce to:

$$E_\theta = A\, Z_o \sin\theta\, j\, \left(\frac{\lambda}{r}\right) \tag{4}$$

$$H_\phi = A \sin\theta\, j\, \left(\frac{\lambda}{r}\right) \tag{5}$$

For these far-field equations E and H are related by a constant, Z_o, defined as the impedance of free space, and E and H are mutually orthogonal. In the far field our concern is the amount of power radiated by the source or the power density at a given distance from the source. This is given by the Poynting vector.

$$\vec{P}_r = \vec{E} \times \vec{H}^* \quad \text{(Poynting vector)} \tag{6}$$

The direction of power flow or propagation as indicated by the Poynting vector is perpendicular to both the E and H fields. Equations (4), (5), and (6) can be combined as given in equation (7).

$$P_r = \frac{1}{2}\frac{|E|^2}{Z_o} = \frac{1}{2}|H|^2 Z_o \quad \text{(Far field, average power density)} \tag{7}$$

Thus, to obtain a measure of the radiated power density in the far field, one need only detect the E field or the H field but not necessarily both. The most common methods make use of E field detectors. This is fortunate because the E field is probably the most biologically significant of the two. Our bodies are most likely E field detectors. H field detectors can be devised but are a little more difficult to manage, and E cross H detectors would be most difficult to construct but are possible by making use of the Hall effect(2).

An instrument designed and calibrated to read power density in the far field will not necessarily read radiated power density when used in the near field. It is assumed that the far field begins where the ratio of E to H is very close to the impedance of free space or 377 ohms. The ratio of E to H, however, is not constant at all positions throughout the near field and will most certainly differ from 377 ohms. Thus, an instrument that responds to the E field will indicate not only the radiated field, but will measure the resultant of the vector addition of all field components given by equations (1) and (2). In the near field a probe will absorb energy by radiationless resonance energy transfer. A simple parallel might be drawn by considering the transfer of energy from the primary winding to the secondary winding of a transformer.

Since the biologically hazardous factor is the E field, it is most fortunate that our instruments detect this quantity rather than the radiated power density. A source of confusion, however, is that the meter readings and the standards for safety are given in mW/cm^2 (the units of power density). These readings should be interpreted as apparent power density or units of $1/2\ E^2/Z_o$, where E is the actual field strength at the point of measurement.

The foregoing explanation is valid for a simple example of the electric dipole, but such an example is not necessarily the most accurate in terms of an approximation to the fields emanating from a microwave oven. A magnetic dipole or slot antenna probably would serve as a better approximation. In this case the roles of E and H are reversed in equation (1), (2), and (3). The multiple source situation of the oven door would actually further complicate the situation.

2.2 THE EFFECT OF ANTENNA SIZE

The exact separation of the near and far field is somewhat arbitrary. The above discussion has implied that the far field begins at the point where the ratio of E to H is very close to 377 ohms. It has also been suggested that the wavelength is the factor that determines the point.

Actually, the size of the antenna also has an important effect. A general understanding of this can be grasped by comparing transmission from a large horn or disc to transmission from a crack in an oven door or from a small electric dipole. Figure 2 illustrates this point.

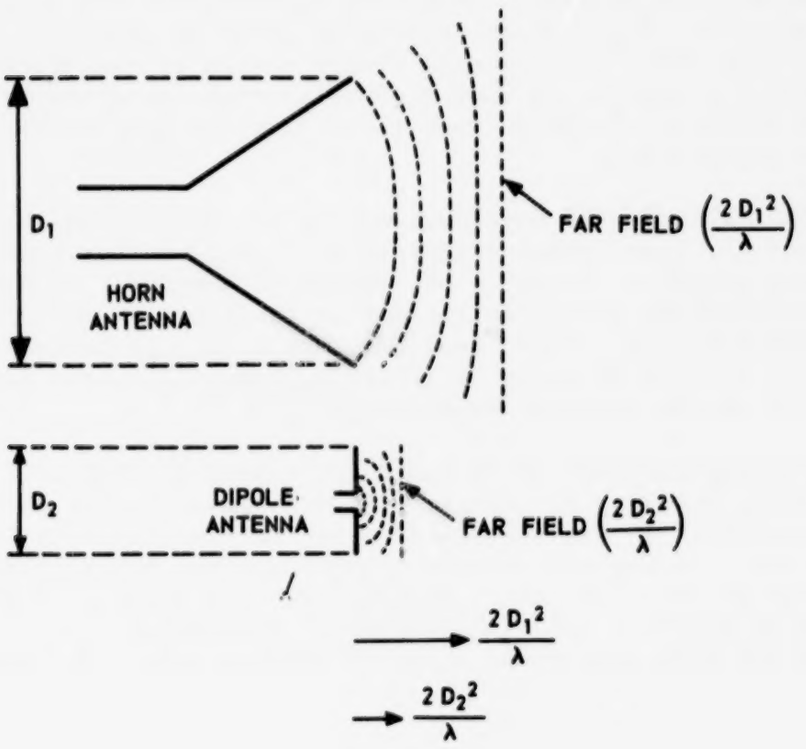


Figure 2. Beginning of a far field.

The large radiator causes field line curvatures further into space; thus, the effect of the nonradiated field will extend further into space from a large antenna.

Since the antenna size is usually the factor which determines how far the near field will extend into space, it seems appropriate to define a separation distance of the near and far field in terms of the antenna size. Such an arbitrary definition is given by the equation $r = 2D^2/\lambda$, where r is the distance from the antenna, D is the antenna diameter, and λ is the wavelength.

The above equation does not give a distance beyond which one will no longer observe effects of the source. In fact, the electric field could differ by 10 to 20 percent from the expected value of a $1/r^2$ calculation.

The term $2D^2/\lambda$ expresses that the phase difference from contributions of all points of the antenna of dimension D will vary by no more than 22-1/2 degrees at the point r.

The $2D^2/\lambda$ approximation indicates the antenna is far enough away to appear to be a point source. It does not, however, imply that the ratio of E to H is exactly equal to 377 ohms. Thus, even though the distance from the source may be several wavelengths, one may still be measuring in the near zone.

The point should be reemphasized that for hazard measurements one should be concerned with the resultant E field. The E field is squared and read out in mW/cm^2 for most hazard instruments. This should be interpreted as an apparent power density and not a true radiated power density.

2.3 ANTENNA IMPEDANCE AND BACKSCATTER

The discussion thus far has been concerned with interpretation of measurements. A problem which is associated with measurements of the near field but which is actually a problem of antenna design is that of backscatter from the receiver probe to the source antenna.

Figure 3 depicts a source with a large conducting antenna in front of it. The antenna or probe will not only absorb energy but will also reflect energy. Energy may be transmitted through the probe region as well. The amount of energy transmitted, reflected, or absorbed by the probe will depend upon the impedance characteristics of the probe. If the probe has infinite conductivity, i.e., has zero resistance, no energy will be absorbed and all the energy will be reflected (large conductive sheet). On the other hand, if the impedance

of the probe were matched to that of free space, i.e., 377 ohms, then no reflection will occur at the boundary. The relative amount that is transmitted through or absorbed by the probe would then depend upon the resistivity of the material versus its other electrical properties.

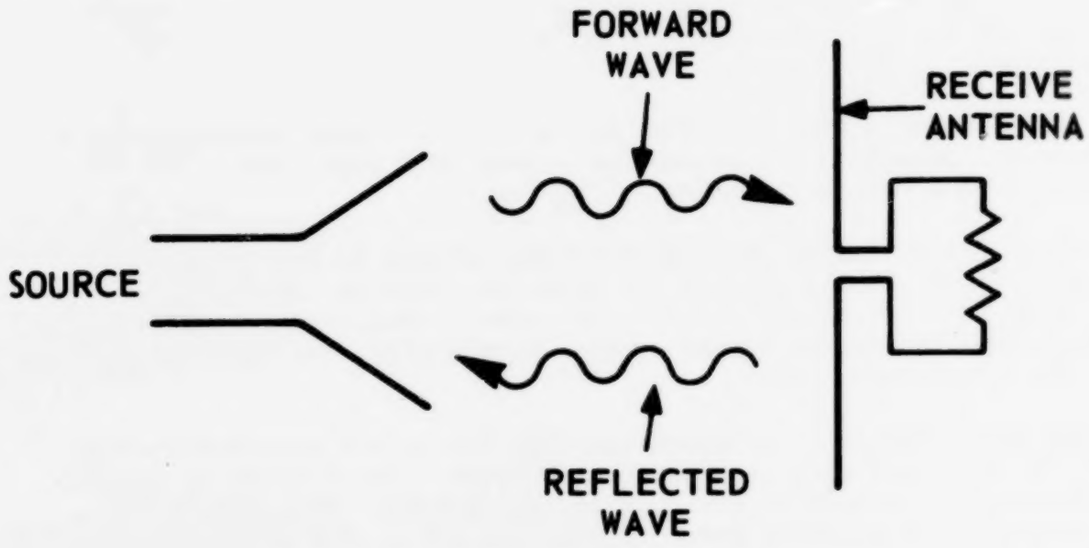


Figure 3. Reflection and standing wave creation by presence of large receive antenna.

The term "probe" in this sense is used very loosely. The mention of size has been avoided. Size becomes a factor only when it affects the impedance, which, of course, is generally the case for all antennas. An antenna which is small compared to the wavelength of the received signal usually has a relatively high impedance. Thus, a small portion of the incident wave is absorbed or reflected by a very small probe.

The particular concern at the moment is the reflected wave. Energy scattered back to the source from the receiver antenna will cause perturbations in the fields at the source and thus, change both the radiated and nonradiated fields. Hence, a large antenna will cause incorrect readings near the source.

The Illinois Institute of Technology Research Institute, under contract to the Bureau of Radiological Health, performed experiments to demonstrate the effect of relative antenna size or impedance on power density measurements[3]. The apparatus shown in figure 4 was used to measure the received as well as the reflected power density. A slot in a large ground plane was used as a source, and a dipole probe was used as the receiver antenna. The rest of the equipment shown made it possible to detect the power reflected back into the source by the presence of the probe. Figure 5 indicates the effect of antenna size on reflected power. Note that for the half wave dipole (quarter-wave wing length) which is the classically desirable length for communication purposes, large variations in reflected power occur as the probe is moved along the slot. As the probe length is decreased, which greatly increases the impedance at that particular frequency, the probe reflects and absorbs less power.

The dipole antenna is of simple construction. The diode is used as a detector, and the leads of the diodes are actually the antenna wings. Figure 6 indicates the effect of antenna length on measured power density as a function of distance from the source. The scale in this figure is given in decibels. One db would represent a variation of about 25 percent. The short or high-impedance antenna gives a fairly smooth curve as would be predicted by equations (1) and (2). A second advantage of the short antenna is its broadband characteristics. A half-wave antenna is highly tuned to a narrow frequency range, and the impedance of such an antenna varies drastically as the frequency of the incident electromagnetic field moves away from the tuned or resonant frequency. A short antenna has a very high impedance, and variations in frequency cause a relatively small percent variation in impedance.

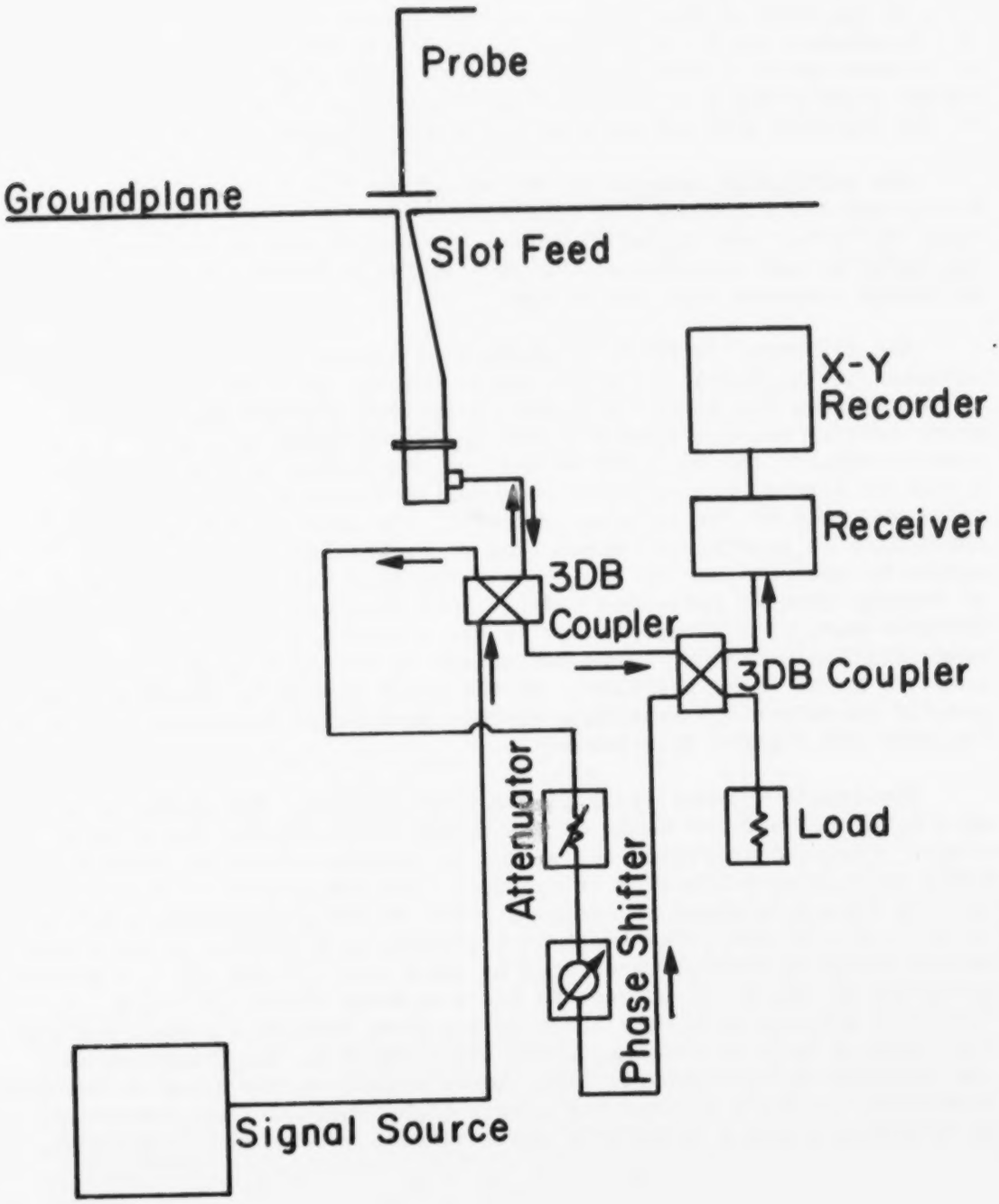


Figure 4. The reflectometer block schematic.

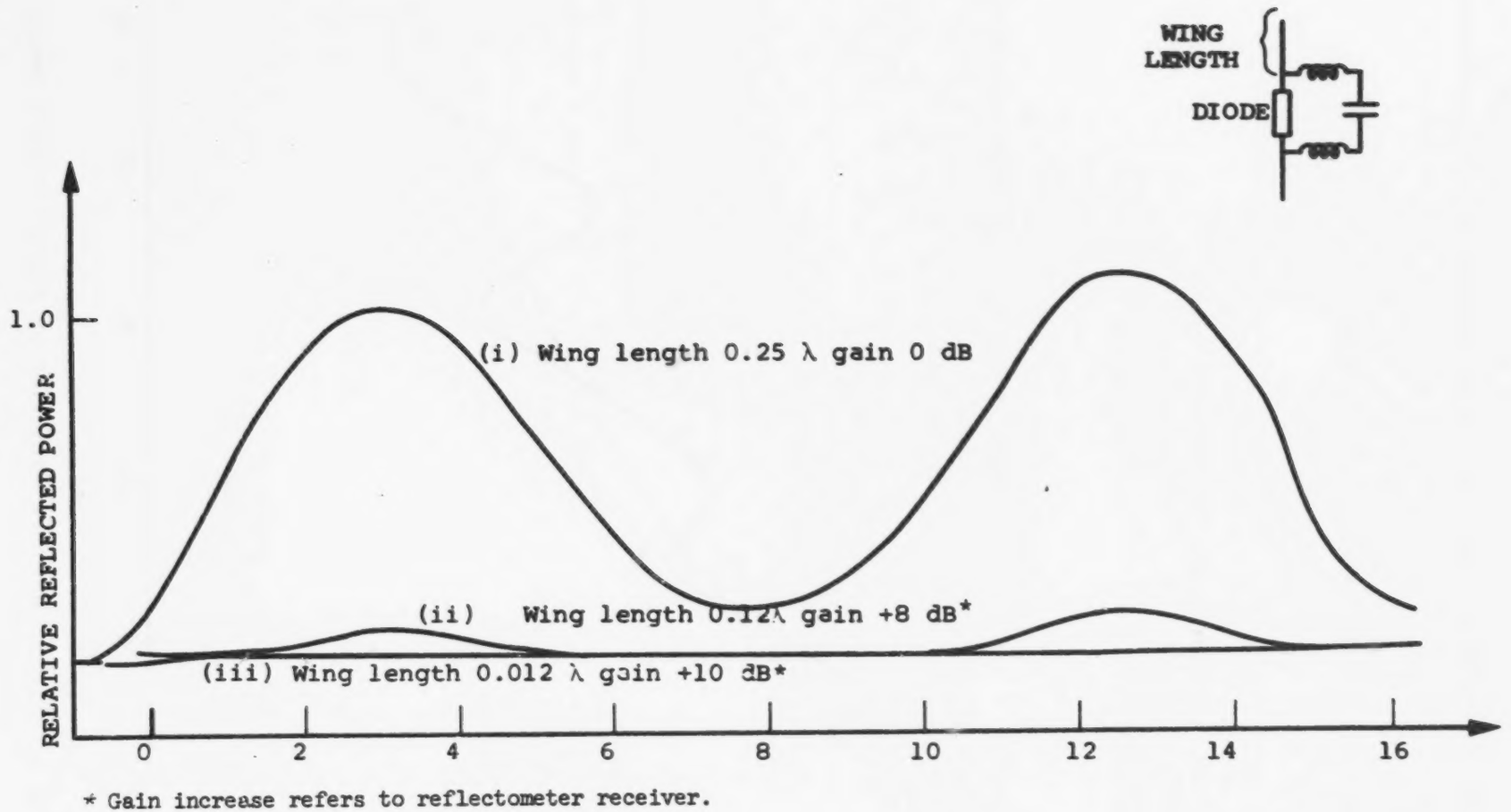


Fig. 5. Relative reflected power when probes of given wing length are passed along slot at 2 cm above ground plane.

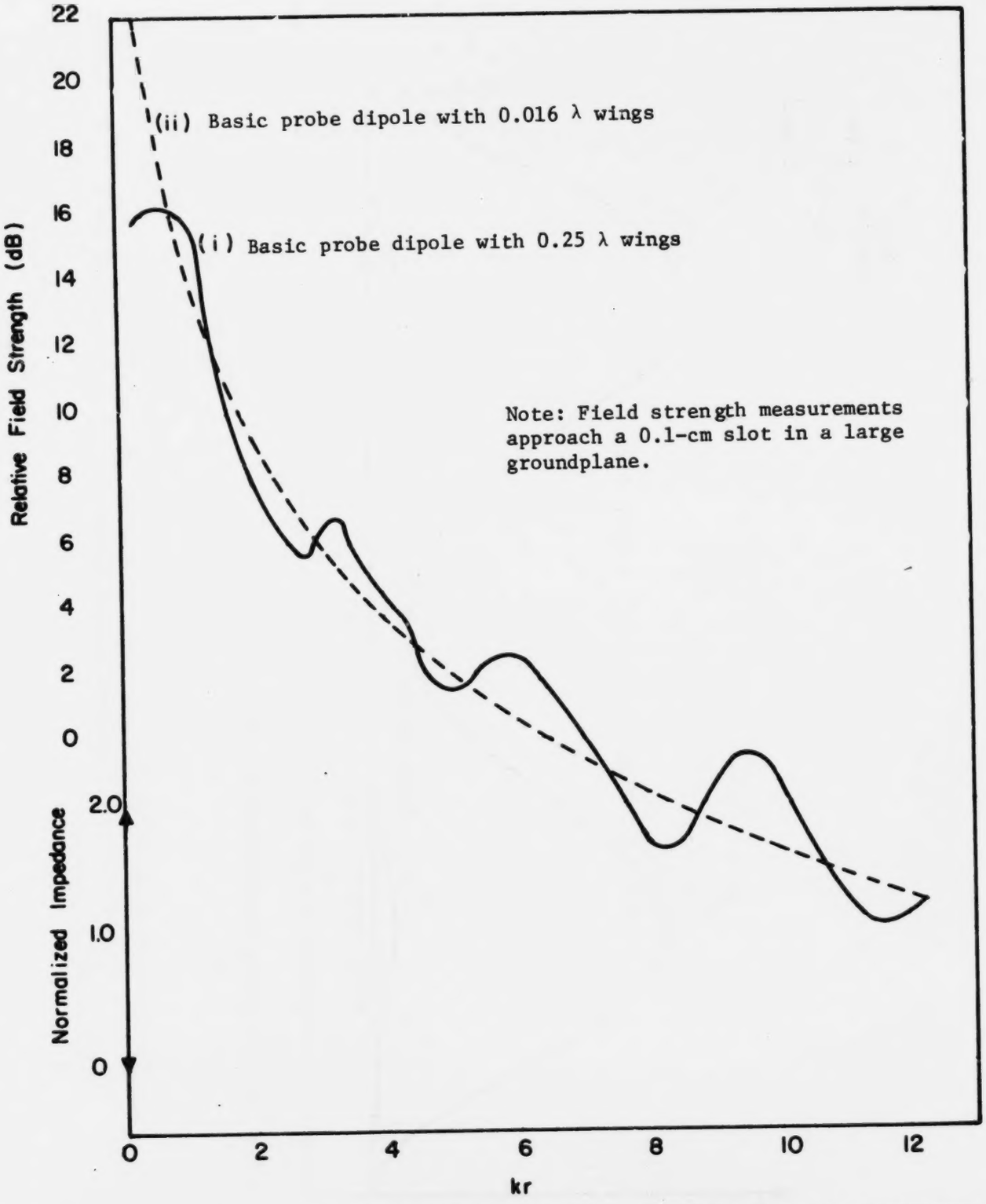


Figure 6. Effect of dipole impedance variation on field strength measurements.

2.4 POLARIZATION

Equation (6) indicated that the directions of the electric and magnetic vectors were mutually perpendicular and that both were perpendicular to the direction of propagation of the electromagnetic wave. Whether the electric vector has a definite orientation or random orientation about the direction of propagations depends upon the nature of the source. For light the source is usually random emissions from molecules which yield random orientation of propagation as well as random direction of the electric or magnetic vector. An exception would be a laser. For microwaves the polarization or orientation of the electric vector is usually not random but has a fixed direction (linear polarization) or a definite rotational pattern (eliptical polarization).

In either case proper design or use of the receiver antenna is necessary. As an example, one may consider an electric dipole as a receiver antenna. If the dipole is held perpendicular to the plane of electric field vibration of a linearly-polarized wave, then no net charge motion would be induced along the dipole element and no field would be detected. On the other hand, an alignment of the dipole with the plane of the E field would result in currents flowing in the dipole and, thus, the field could be detected. Similar analogies can be drawn for right- and left-handed circular or eliptical polarization. A right-handed polarized antenna will not receive a left-handed polarized wave.

This difficulty can be overcome in two ways. The first is by proper measurement technique and the second, the more desirable, is by proper instrument design. Complete measurements of the total field can be made with a single dipole by taking three measurements with the dipole oriented in three orthogonal directions. Only two measurements are necessary if the direction of propagation is known and the field is a plane wave. A true reading of the field strength or power density can be obtained in this manner, even in the presence of eliptical polarization. If the meter in use is reading power density (i.e., E^2/Z_o) one need only add the three (or two) components to obtain the desired total power density.

By using a probe which contains three mutually orthogonal dipoles, the necessity of relying on the skill of the operator to obtain accurate measurements of the total field can be eliminated. In this case the total $E_x^2 + E_y^2 + E_z^2/Z_o$ can be obtained electronically.

3. MICROWAVE DETECTORS

3.1 TYPES OF DETECTORS

The problems of reception of a microwave signal with an antenna have been discussed. Once the energy is received by the antenna, it must be converted in some manner by a detector to a direct current in order to obtain a readout. All of the devices used in microwave detection can be separated into two categories. First are the devices which measure microwave power by sensing a change in temperature due to the absorption of energy. The second type of device produces a detectable current or voltage related to the electromagnetic energy. In the first class are bolometers and thermocouples. Bolometers (thermistors, barretters, etc.) operate on the principle that a resistance change with temperature in the bolometer device is measurable by means of a sensitive bridge circuit. The thermocouple, on the other hand, produces a d.c. voltage as a result of the rise in temperature caused by the absorbed microwave energy and has the advantage of requiring only a millivoltmeter to determine power density. The circuitry of the millivoltmeter is much simpler than the complex bridge circuitry used with the bolometer. The disadvantages of these two devices are that they respond to any form of heating, are subject to burnout if overloaded, and have a relatively slow response. The problem of meter reading variations due to ambient temperature fluctuations can be considerably reduced through the use of more than one detector in a differential configuration and more complicated associated electronic circuitry.

The primary example of the second class of detectors, the current- or voltage-producing detector, is the diode. A semiconductor diode can be used to detect microwave energy by making use of its nonlinearity to convert a microwave signal to a d.c. signal. The diode has a region of "linear" detection and a region of "square law" detection. The former occurs for signals of approximately 5 mW or greater, and the latter for inputs of approximately 0.1 mW or smaller. These numbers vary according to the type of diode and associated circuitry being used. The square law region provides direct power measurement. If operated in the square law region, a limited range and power measurement capability is provided. However, some diodes are more rugged than the temperature-sensitive devices. Excessive signal causes only an incorrect reading rather than burnout. Signals above the rated input value would cause the device to leave the square law region and enter the linear or quasi-linear region and give an uncalibrated reading. The linear region can also be used for detection with the proper associated electronic circuitry. In this case the values of the detected E fields must be squared before they are added and read out.

3.2 INSTRUMENT RESPONSE TIME

As the term implies, the response time refers to the time required for an instrument to respond to an input signal. A more precise definition would be the time required for the instrument to respond to 90 percent of the final value of a step input signal. The effect of the instrument response time on the measured power density is of particular concern.

An example, such as the Narda 8100 which provides a setting for two different response times, can be used to illustrate the effect of response time on the recorded value. Figure 7 presents the response time of the Narda 8100 to a step input signal. The data(4) were obtained by making use of a video tape recorder and a closed-circuit TV system along with a microwave generator capable of producing a peak value in a few milliseconds. Note that the system responds to 90 percent of the final value (20 mW/cm^2) in approximately 1 second. Figure 8 gives data for the same instrument set for the slow response. About 6 seconds are required to reach 90 percent of the final value. Figure 9 illustrates the effect of the two response settings presented in figures 7 and 8 on the measurement of leakage from an oven with low-frequency stirring. The slow response tends to give an average value and remove the peaks which are clearly indicated when the fast response is used. In this case the fast response is also averaging. For example, the magnetron of this particular oven has a 60- or 120-Hz modulation which does not show up at all in this particular reading. In a sense, the establishment of the response time of the instrument dictates the amount of averaging that is allowed.

The present standard for microwave ovens states that an instrument with a zero to 90 percent response time of 3 seconds will be used for surveying. The 3-second criteria is a compromise between long averaging periods, which may endanger the operator and not correspond to the biological hazard, and short response times which make accurate interpretation difficult due to rapid meter movement. If it is determined that in some cases the peak power is truly the biologically significant factor, then all meters used for monitoring those cases should be modified to read peak power.

3.3 POWER DENSITY INSTRUMENTATION

An ideal instrument for hazard survey purposes would be one that would measure E^2/Z_o with the introduction of an insignificant perturbation in the electric field. For this to be accomplished with no prior knowledge of the field, an instrument must have the following properties:

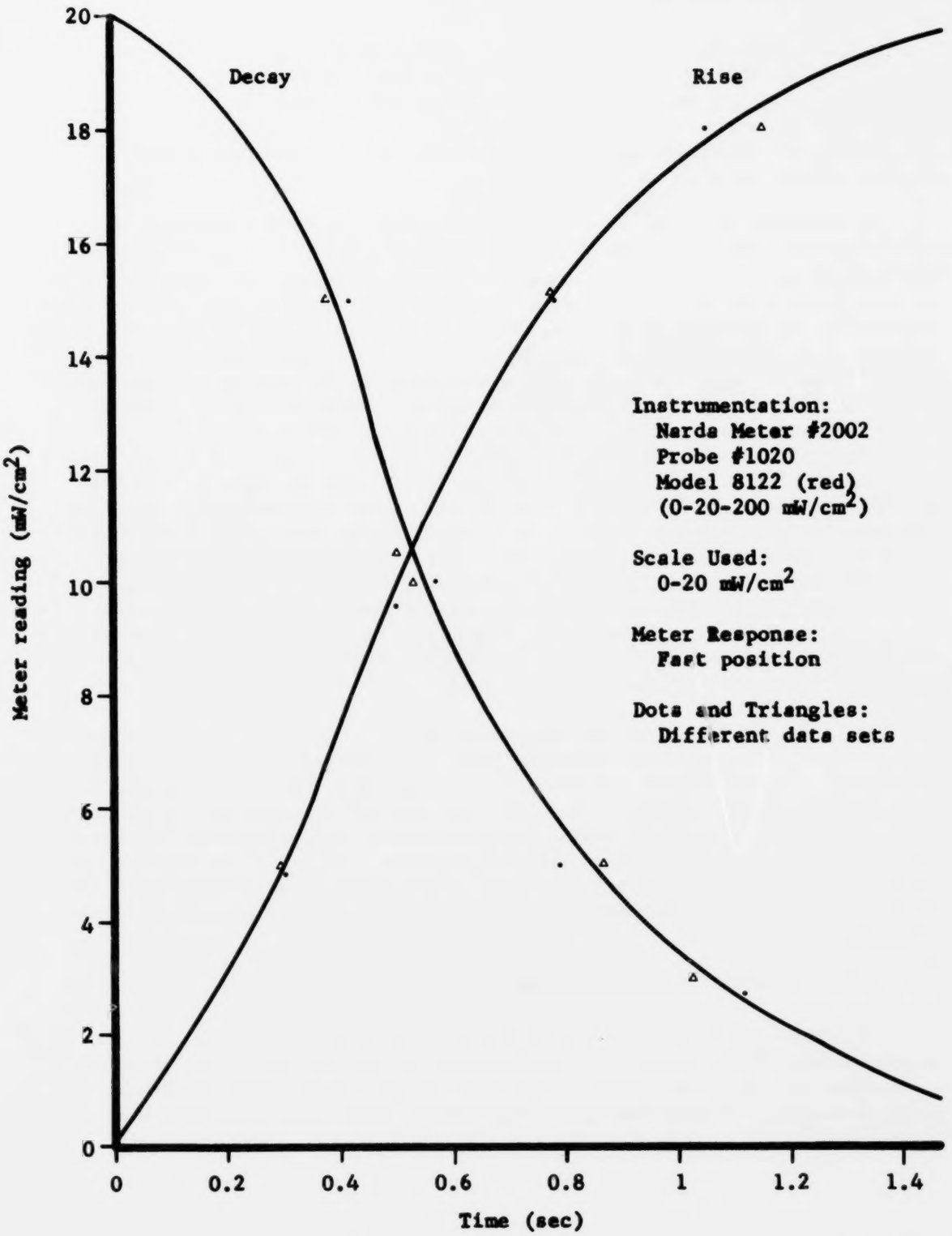


Figure 7. Fast response of Narda 8100 to stepped RF input, Model 8110-8122 combination.

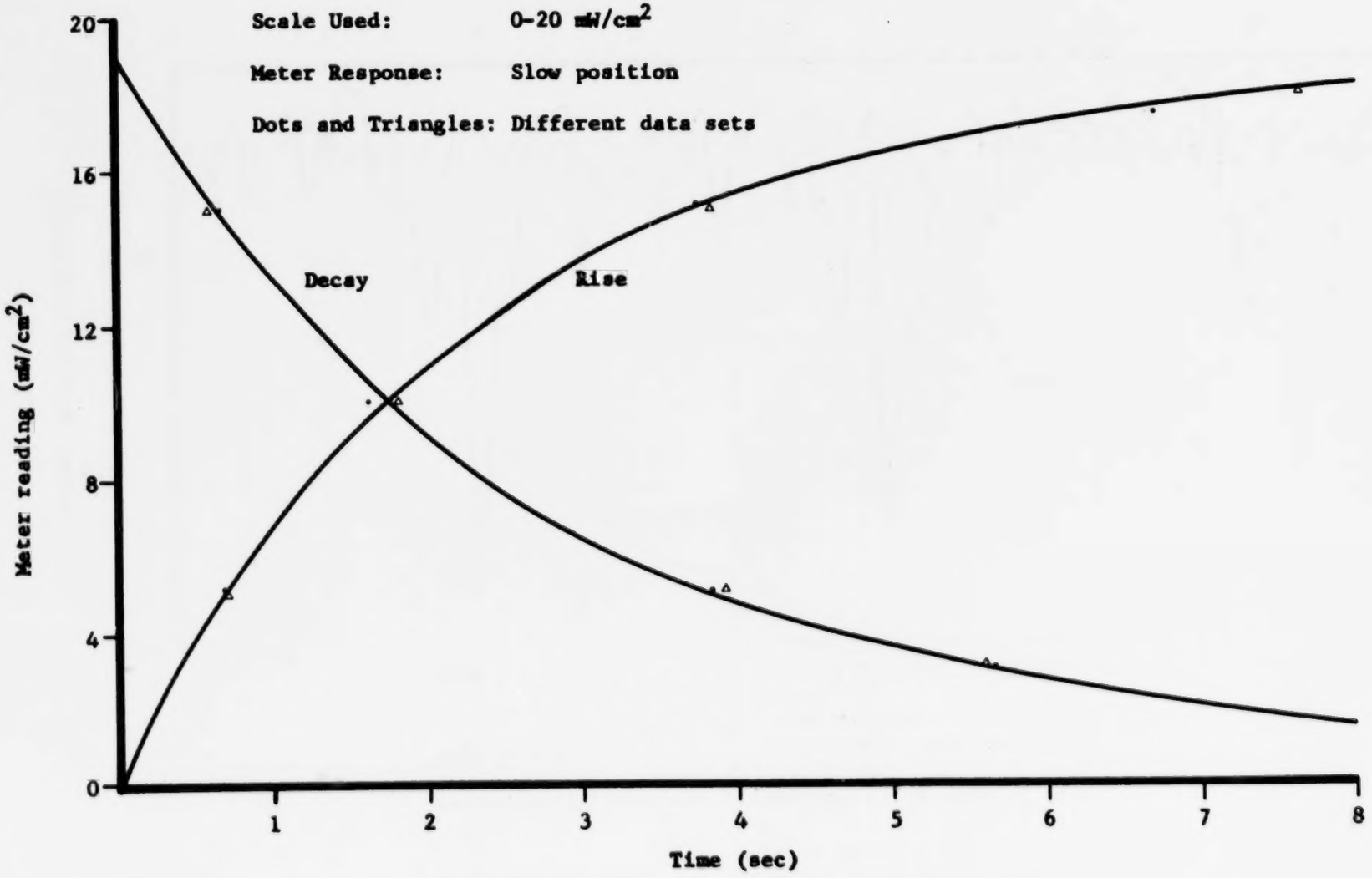


Figure 8. Slow response of Narda 8100 to stepped RF input, Model 8110-8122 combination.

Instrumentation:	Narda meter Model 8110 Probe Model 8120
Measurement position:	Maximum along edge of door
Type oven:	Double magnetron and double fan stirrer
Test:	Fabricated test condition for easy detection of level

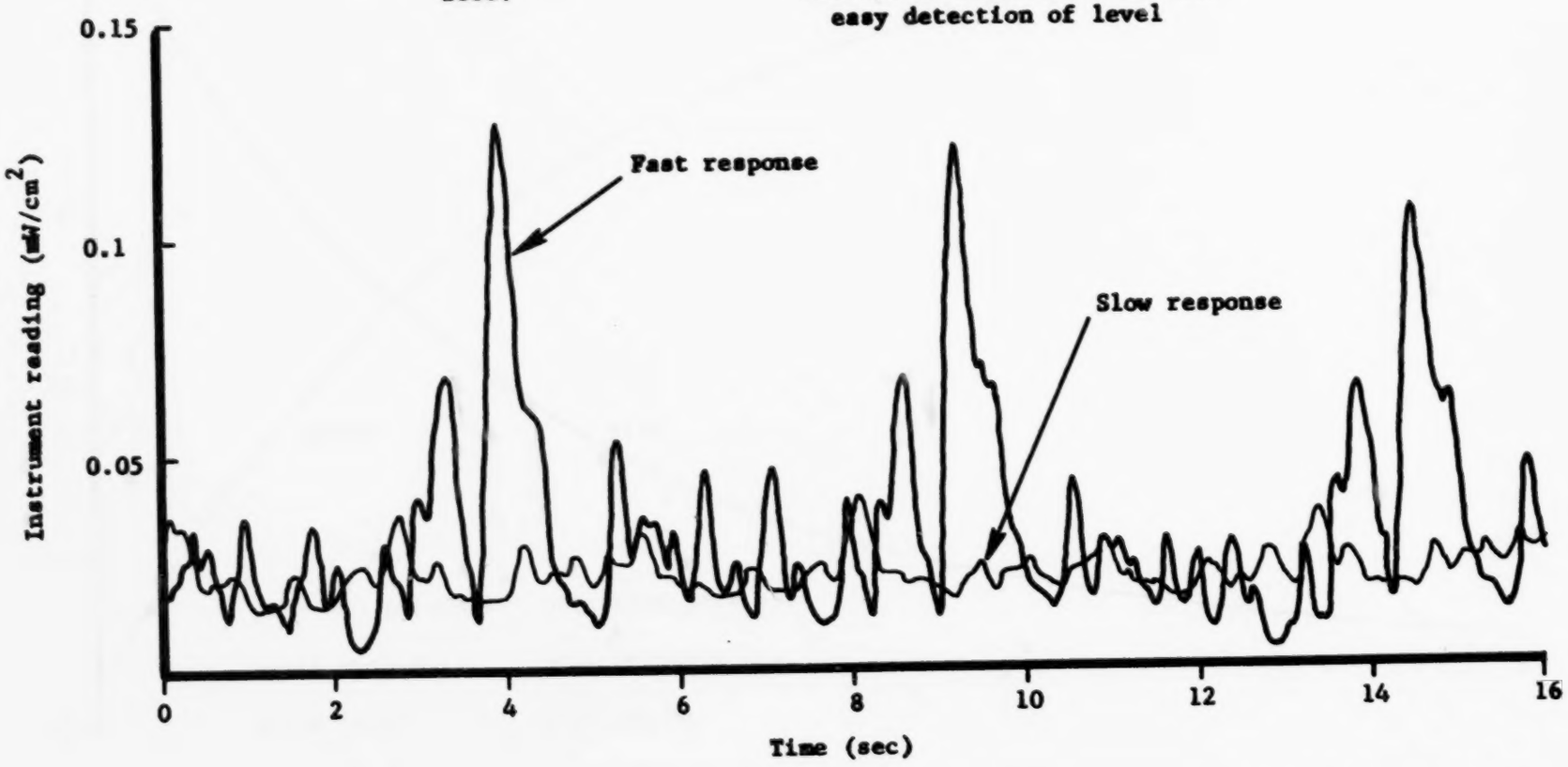


Figure 9. Instrument reading as a function of time (fast and slow response): double fan stirrer.

(1) The antenna probe must be electrically small or the impedance should be so matched so as to cause no backscatter from the probe to the source.

(2) The antenna/probe should be as close to an isotropic receiver as possible.

(3) The antenna/probe should be sensitive to all polarizations of incident electromagnetic fields.

(4) The instrument should be capable of giving accurate readings with simple operation.

(5) The response time should be variable or provide a 0 to 90 percent response of 3 seconds to meet the requirements of oven standards.

(6) The frequency response should be broadband so as to provide coverage over the widest possible frequency range.

No instrument presently exists which meets all of the above criteria. Several instruments which partially meet these criteria are under development, and at least one is on the market. An example is the Narda Electromagnetic Survey Meter model 8100.

3.4 THE NARDA 8100 - A THERMOCOUPLE DETECTOR

The Narda 8100 instrument is calibrated to operate at two given frequencies, 915 MHz and 2450 MHz, with a switch provided to change frequencies. An antenna extension is also necessary when operating at 915 MHz. This system is depicted in figure 10. The readout is directly in mW/cm^2, and the three probes shown give a range of 0 to 0.2, 0 to 2, 0 to 20, and 0 to 200 mW/cm^2. Each probe provides two of the aforementioned scales. Measurements are independent of x, y polarization of incident radiation propagating in the z direction. This is accomplished by using crossed dipole elements as indicated in figure 11. The components of the E vector will be properly added regardless of the polarization, provided the squares of the E components are added. The simple addition of the magnitude of the vector components of E would create an eliptically-polarized receiver.

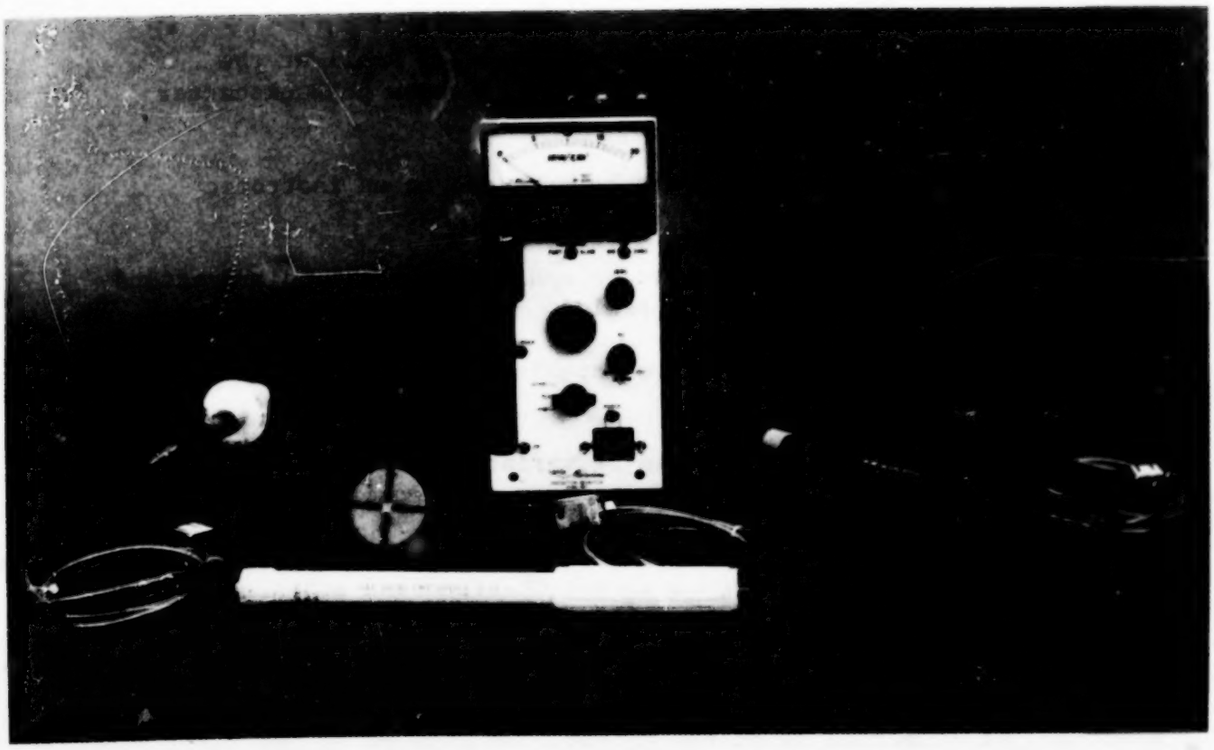


Figure 10. The Narda 8100 system.

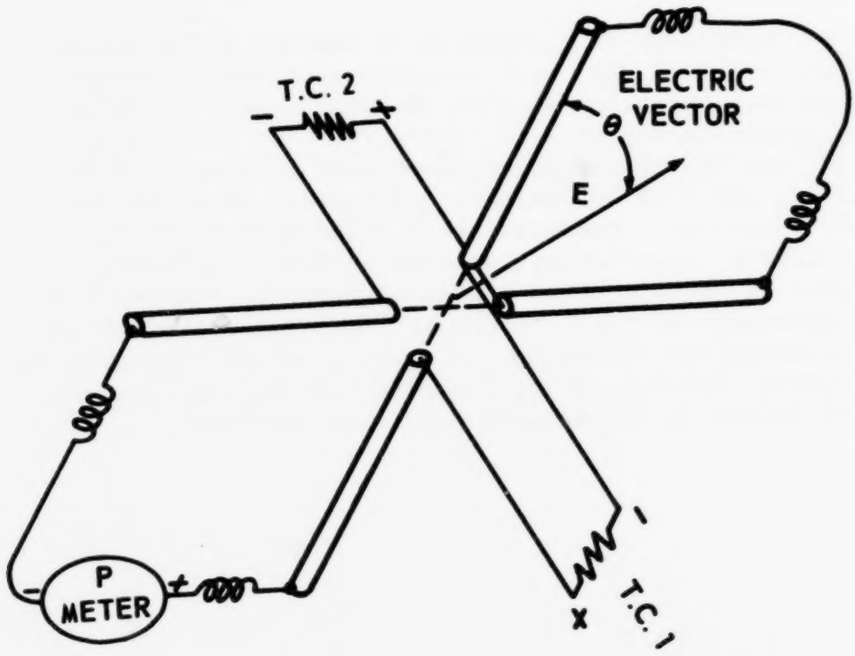


Figure 11. Crossed dipole elements.

The success of this probe stems from its novel use of thin-film vacuum-evaporated thermocouple elements which function as both antenna and detector. The manufacturer claims temperature insensitivity due to the close proximity of the hot and cold junctions. These elements will respond to infrared radiation. The possibility of detecting infrared rather than microwave frequencies is eliminated by the use of a styrofoam spacer which functions as an infrared shield as well as a distance guide for survey measurements. The spacer used for 915 MHz also contains antenna extensions to provide more sensitivity at the lower frequency.

The winglengths are electrically short (0.06 λ at 2450 MHz and 0.075 λ at 915 MHz), and thus backscatter is minimized. The results presented in figures 5 and 6 indicate that even shorter winglengths, particularly at 915 MHz, may be desirable. The use of this instrument has not indicated that backscatter is a problem.

The specified accuracy of this instrument is $\pm$ 1 db. The response was presented in figures 7 and 8. At present the fast response must be used to conform with the standard for leakage measurements for microwave ovens.

3.5 DIODE DETECTOR INSTRUMENTS

The Bureau of Radiological Health contractually supported the development of two microwave power density detection instruments which make use of diodes as detector/antennas. These instruments were developed by the Illinois Institute of Technology Research Institute (IITRI) and the National Bureau of Standards (NBS)[7].

The instrument developed by IITRI and described in reference[3] is depicted in figure 12. The probe uses orthogonal dipoles with diodes operating in the square law region. The antenna and detector diode detectors are located in the small device shown in the foreground of figure 12. This device is about 1 cm across. Since the diodes are operated in the square law region, the signals can be immediately added; only two leads are needed from the detector lead back to the readout instrumentation.

The probe is capable of measuring over a dynamic range in excess of 40 db. The maximum power density measurable is about 25 mW/cm^2. Above this value the diodes of this instrument leave the square law region. The addition of the unsquared components of the E vector will yield an incorrect reading.

Figure 12. IITRI instrument

The crossed dipoles again provide polarization insensitivity in the x, y plane for probe handle orientations along the z direction, as long as the square law region is not exceeded.

Figure 13 shows a schematic of the device. A minimum amount of circuitry is needed. The probe circuitry, consisting of two diodes, four resistors, and a capacitor, is all contained in the small device in the foreground of figure 12. The control box contains two resistors providing for three dynamic ranges. Essentially these are 0 to 0.25 mW/cm^2, 0 to 2.5 mW/cm^2, and 0 to 25 mW/cm^2. This device is very broadband due to the shortness of the antennas. A variation of only 10 percent would be incurred for measurements ranging from 915 to 2450 MHz. However, a third resistor can be switched in at 2450 MHz to provide calibrated readings at both 915 MHz and 2450 MHz. The small size of the dipoles (0.8 cm overall size) makes backscatter negligible.

The major problem with this developmental probe is the matching of the two diodes for perfect polarization insensitivity. The two diode/antennas must be perfectly matched in power and in frequency response. So-called matched diodes purchased off the shelf are usually matched at d.c. or audio frequencies and thus are not necessarily matched at frequencies in the GHz range.

A millivoltmeter can be used as a readout circuit. The readout meter shown in figure 12 was developed by the staff of the Division of Electronic Products.

Details of the IITRI instrument are presented in reference (3).

The major differences between the probes developed by IITRI and NBS are that the NBS probe has three orthogonal dipoles and the diodes are operated over all three regions of diode response -- square law, transition, and linear. Also, the dipole antennas are more than twice as long as those of the IITRI probe so as to provide more signal.

The use of the three orthogonal dipoles along with the high-resistance feed line developed previously at NBS allowed the construction of a polarization-insensitive receiver with nearly isotropic response. The three dipoles should allow an exact measure of E^2 (I.e., $E_x^2 + E_y^2 + E_z^2$) regardless of polarization or direction of propagation. Such a probe is particularly useful in measuring fields close to multiple sources where the nonradiating field does not present a clearly defined wavefront. The construction of a single dipole is depicted in figure 14. The configuration of the diode and high-resistance lead wire is also shown.

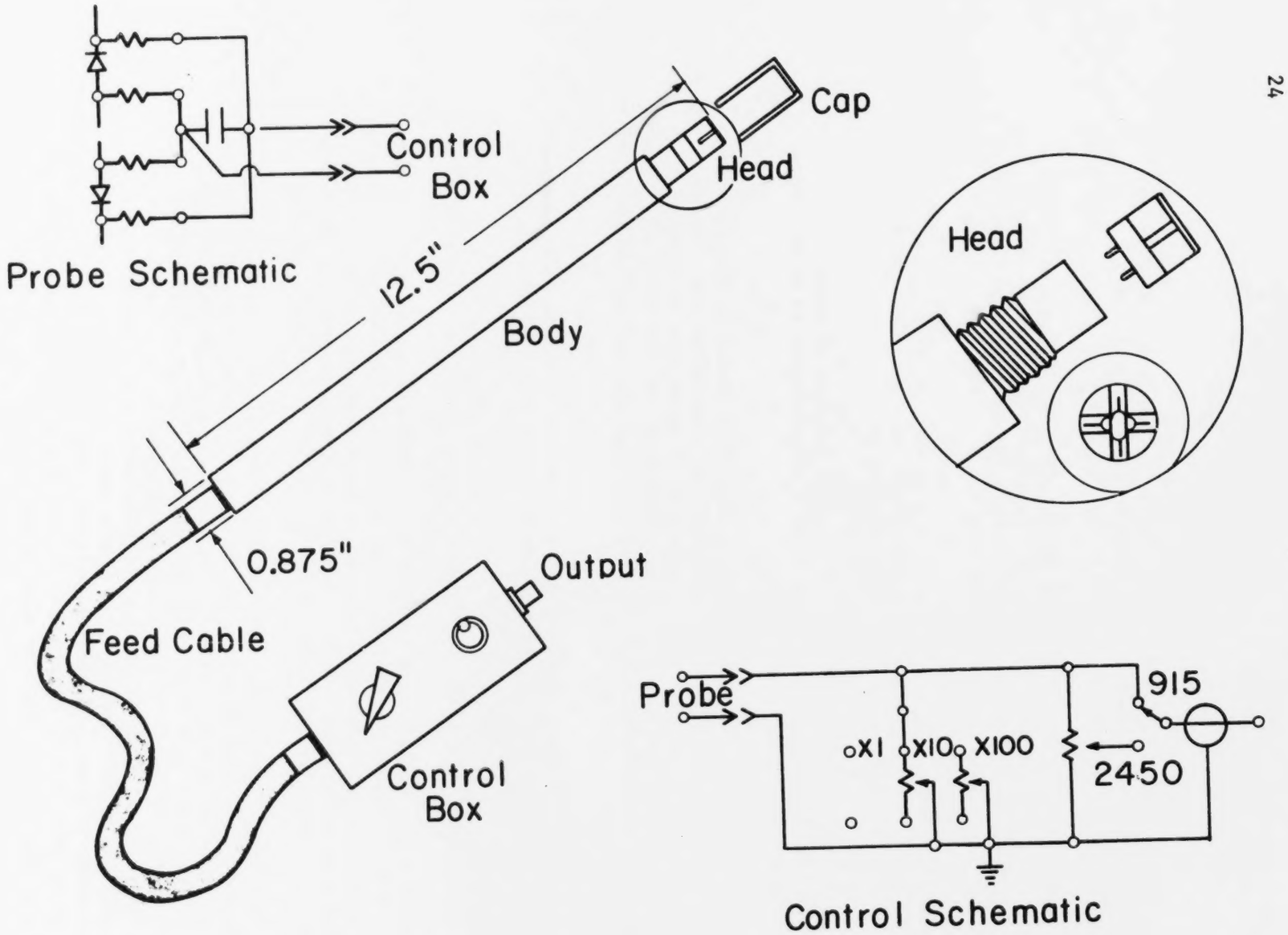


Fig. 13. Schematic of IITRI near-field instrument.

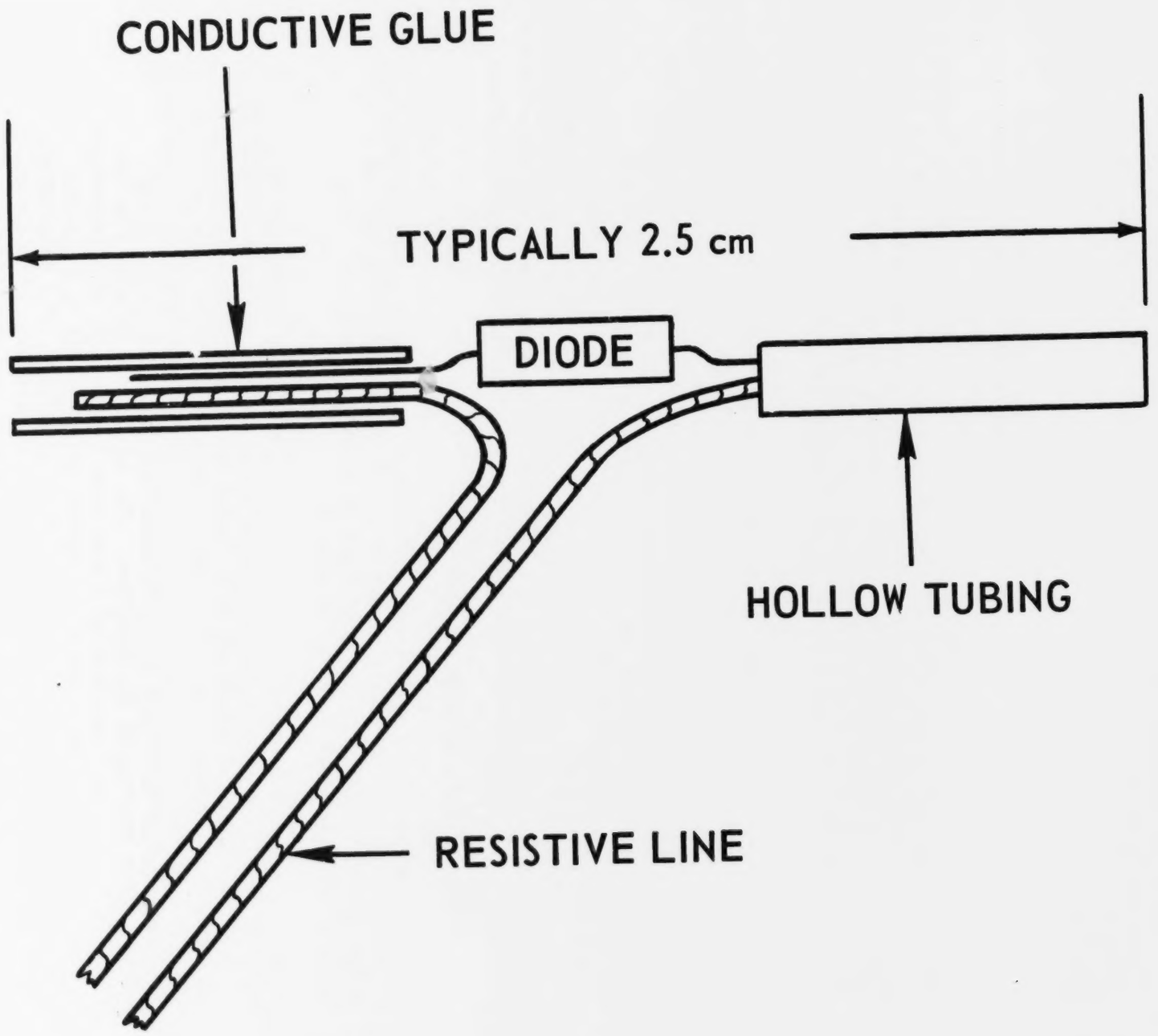


Figure 14. Schematic of an individual receiving dipole.

The high-resistance transmission line (about 700 ohms/cm) is of Teflon impregnated with carbon and covered with a film of nylon. The diameter of the conductor is about 0.03 inch, and the nylon film is about 0.005-inch thick.

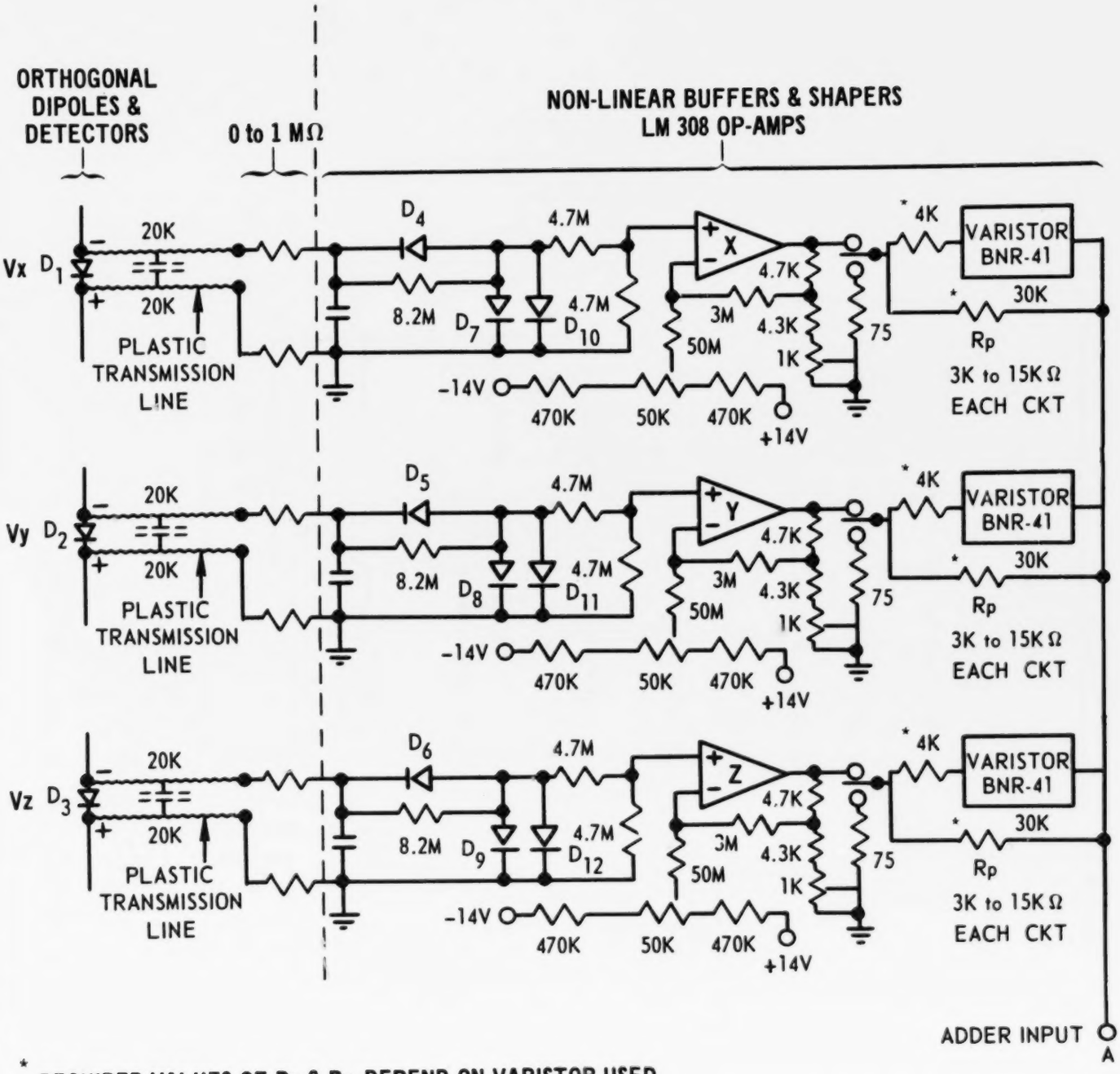
The two conductors from each diode are formed into a parallel-wire transmission line to minimize differential mode noise "pickup". These high resistance transmission lines produce very little distortion of the field and also produce very little interaction with the dipoles. The lines may give noise problems, however, if not kept rigid. The The three transmission lines are formed into a bundle and withdrawn from the set of dipoles at equal angles from each dipole to minimize and balance any interactions between the lines and the dipoles. The transmission line also acts as an output filter for the rectified RF voltage.

Since the probe operates above the square law region of the diode, fields up to 2 W/cm^2 can be read. The price paid for this upward extension of the range is that an increased amount of circuitry is needed. First, circuitry must be developed to match the response of the diode over the three regions mentioned above. Second, all signals must be squared and added to obtain the proper value of $E^2 = E_x^2 + E_y^2 + E_z^2$. The circuitry developed by NBS for this purpose is presented schematically in figures 15 and 16. The antenna includes detector/diodes and 20 Kohms (about 1 foot) of high resistance line. The four diodes between S1 and the first operational amplifier are used for shaping the low-level response and the varistor network is used for shaping the high-level response.

3.6 LIQUID-CRYSTAL DEVICES

A prototype model of a liquid-crystal microwave power density meter has been developed by Bendix Research Laboratories for the Bureau of Radiological Health[5]. The prototype is shown in figure 17. The basic construction is shown in figure 18.

A thin, 0.0005-inch-thick, sheet of Mylar tightly stretched in a rectangular plastic frame serves as the basic support structure. One side of the Mylar is metalized with a thin layer of nichrome to a resistivity of approximately 377 ohms per square. A thin layer of liquid crystals is applied to the opposite side of the Mylar. Energy from an incident microwave field is absorbed by the metalized layer, resulting in heating of the membrane. The scattering of light by the liquid crystals is a function of temperature. Thus, as the temperature is raised (in this case from 38° to 39°C), the color of the crystal changes from red to green to blue and then to purple. The temperature and color distribution over the membrane are, therefore, directly related to the microwave field strength. The membrane provides a graphical real-time depiction of the field strength over its entire area.



* REQUIRED VALUES OF Rs & Rp DEPEND ON VARISTOR USED

ALL TWELVE DIODES ARE HP2800

Figure 15. Energy density meter: antenna and antenna follower circuits.

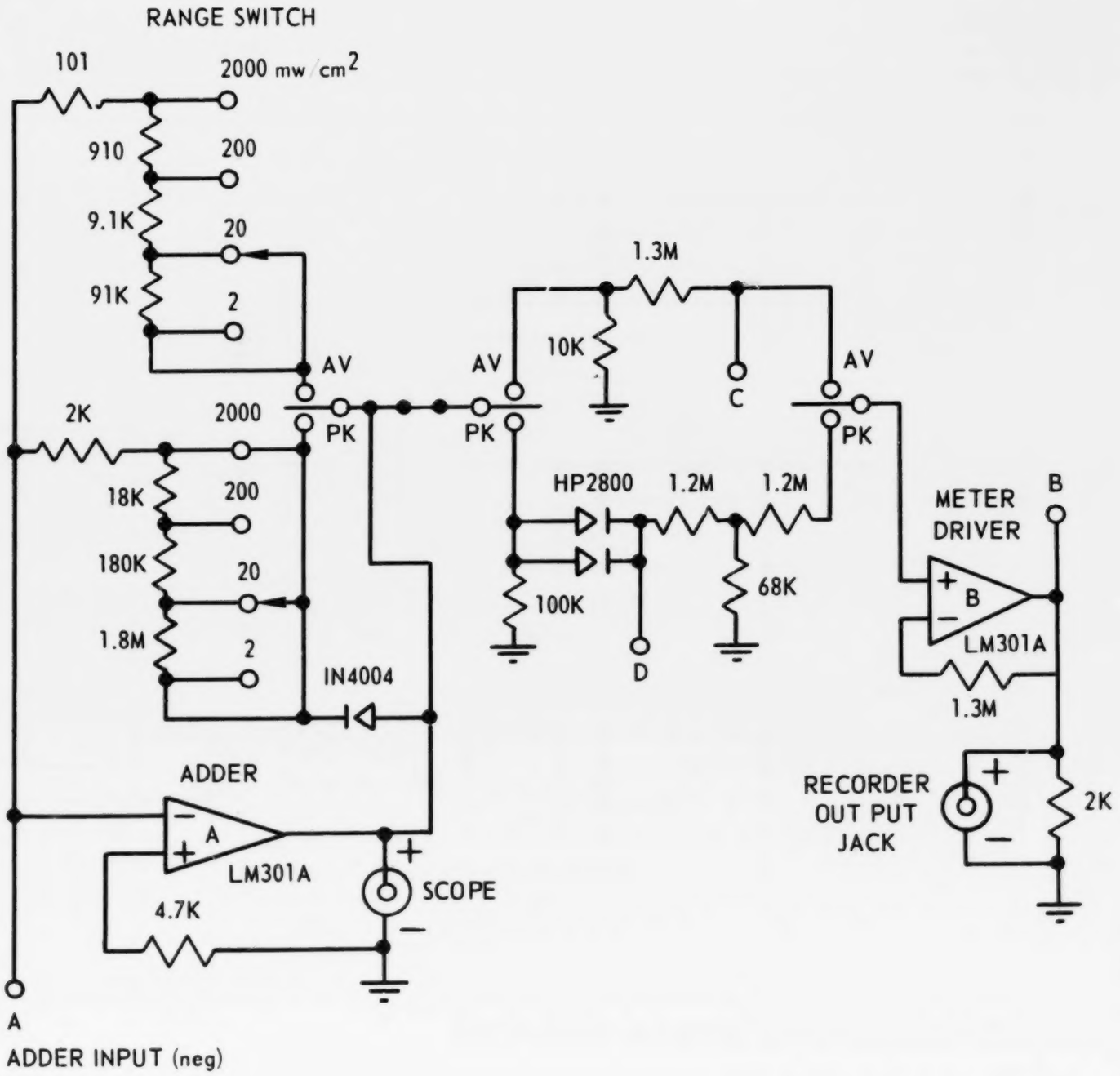


Figure 16. Energy density meter: additional circuitry.

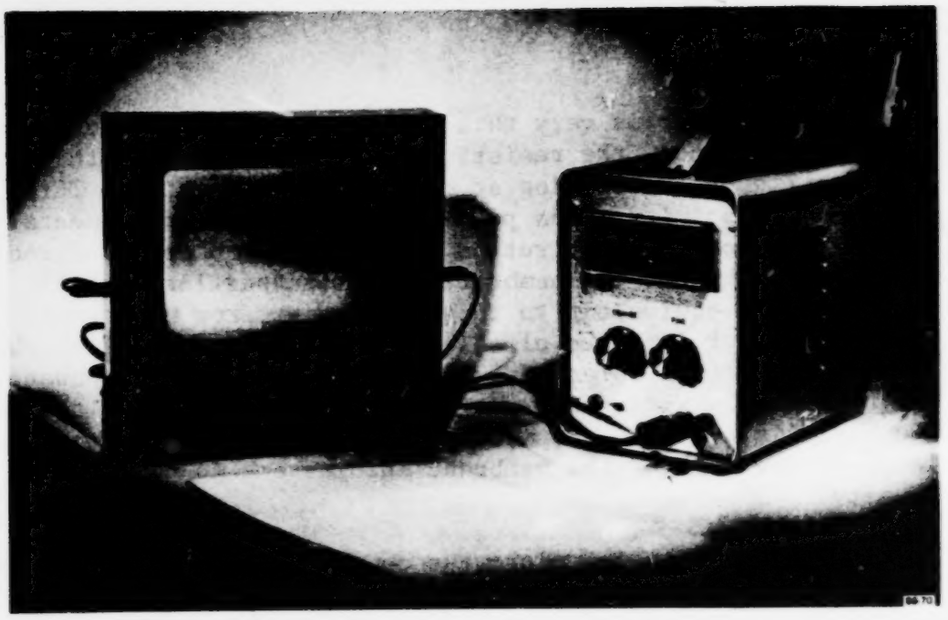


Figure 17. Complete power density meter.

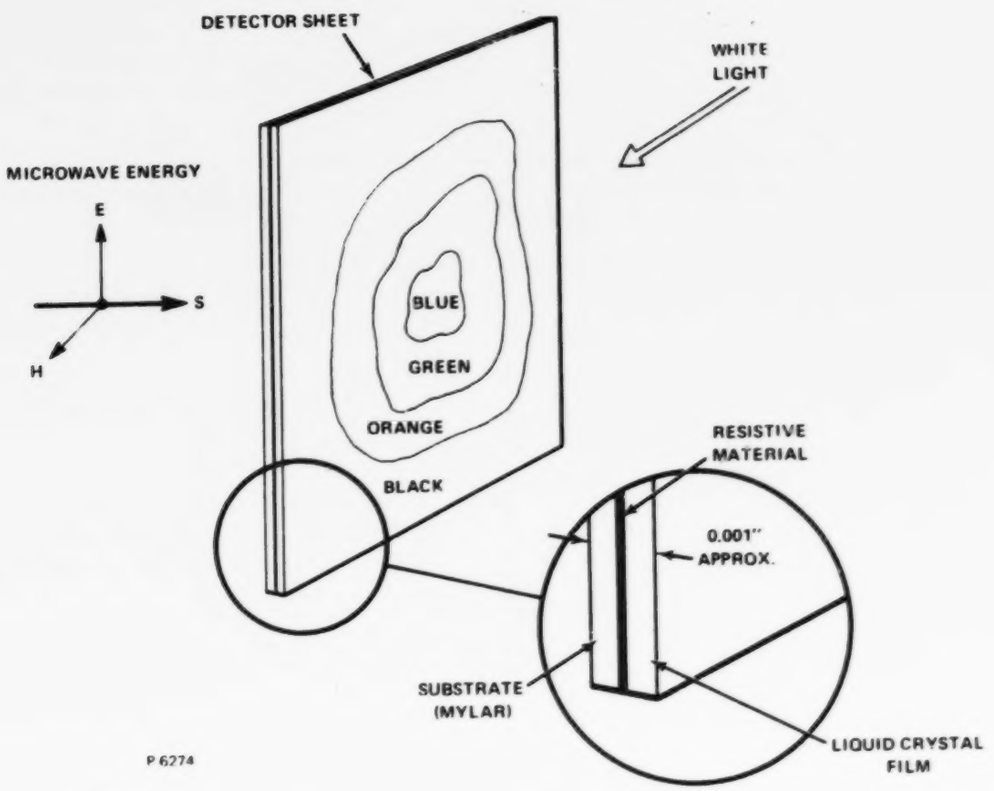


Figure 18. Basic construction of membrane.

The nichrome layer is very thin compared with skin depth at microwave frequencies. Hence, the resistivity is the same for both direct currents and currents oscillating at microwave frequencies. This equivalence in resistivity makes possible a simple and fundamental method of calibration by substitution. A precisely-measured direct current is passed through the membrane to obtain heating effects, as evidenced by color, equivalent to those resulting from microwave currents. The direct currents also serve as a biasing means to obtain the liquid-crystal color threshold. The difference in bias power levels required to produce a given color at one location with and without a microwave field is equal to the microwave power absorbed at that location. A knowledge of the area of the membrane enables one to calculate the power density.

The parameters affecting microwave power absorption by the membrane can be emphasized by using the analogy between plane-wave free-space propagation and transmission lines. This analogy is illustrated in figure 19, where the membrane has a resistivity equivalent to free space, i.e., 377 ohms per square, and the resistive film is thin compared with the skin depth. The membrane is backed by a parallel metal conductive

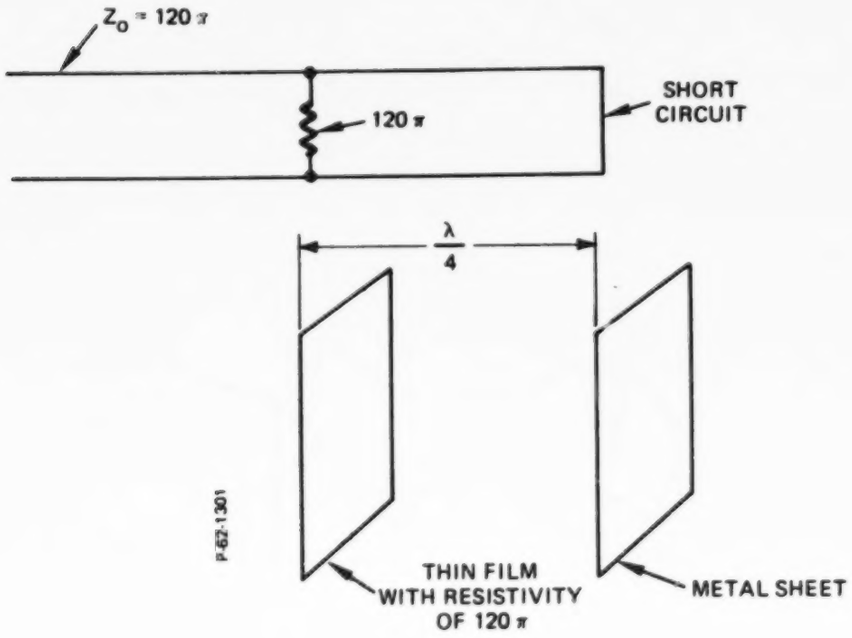


Figure 19. Analogy between plane-wave free-space propagation and transmission lines.

plate which has a very low resistivity. When the spacing between the metal conductive plate and membrane is one-quarter wavelength, all incident microwave energy propagating in a direction perpendicular to the plane of the membrane is absorbed by the membrane. Transmission line theory states that all energy propagating down a transmission line having a characteristic impedance of 377 ohms and terminated by both a shunt 377-ohm resistor and a quarter-wavelength short circuit will be absorbed by the resistor. Absorptivity does not vary rapidly with incident angle; angles up to 20 degrees from normal decrease the absorptivity by only about 1 percent.

In practice, the metal sheet shown in figure 19 is replaced by a sheet of glass with a low-resistivity, transparent, tin oxide film on one surface. This special glass permits observation of the nonexposed side of the membrane and also shields the operator from potentially hazardous radiation.

Liquid-crystal preparations that are very sensitive and will change colors noticeably with temperature changes of as low as about 0.1°C are acceptable microwave indicators for this instrument. Their use results in a sensitivity generally better than that required for oven leakage measurements.

The time constant of this liquid-crystal device is limited by the thermal capacity of the liquid crystal and its incapsulation. Most of the heat capacity can be attributed to the latex binder and the material used in making microcapsules for the liquid crystal.

Further development of this instrument is necessary before it can become useful as a survey tool. Such problems as uniform deposition of the nichrome coating, baffling from infrared radiation, and selection of a low-heat-capacity binding material for a faster response must be solved before this instrument can be manufactured.

REFERENCES

(1) DRERHAGE, KARL H. Monomolecular laser and light. Sci. Amer. 227: No. 3 (1970).

(2) RUGARI, ANTHONY D. A Hall effect microwave power meter. ASTIA Document No. 257311.

(3) RUDGE, A.W. and R.M. KNOX. Near field instrumentation. Report No. BRH/DEP 70-16, USDHEW, Public Health Service, Bureau of Radiological Health, Rockville, Md. (July 1970).

(4) DIVISION OF ELECTRONIC PRODUCTS. The effect of instrument averaging time on microwave power density measurements. Report No. BRH/DEP 70-12 USDHEW, Public Health Service, Bureau of Radiological Health, Rockville, Md. (June 1970).

(5) ASLAN, EDWARD. An electromagnetic-radiation survey meter. IEEE Transactions on Instruments and Measurements (special issue of Conference on Precision Electromagnetic Measurements). To be published November 1970.

(6) BENDIX CORPORATION RESEARCH LABORATORIES. Development of liquid crystal microwave power density meter. Report No. BRH/DEP 70-8, USDHEW, Public Health Service, Bureau of Radiological Health, Rockville, Md. (May 1970).

(7) NATIONAL BUREAU OF STANDARDS. Second annual progress report on electromagnetic hazards project, NBS Technical Note 9761.

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MICROWAVE MEASUREMENTS AND NEW TYPES OF DETECTORS FOR EVALUATION OF HEALTH HAZARDS.
U.S. Department of Health, Education, and Welfare, Public Health Service, Bureau of Radiological Health Publication No. BRH/DEP 71-1 (January 1971), 33 pp. (limited distribution).
ABSTRACT: This report discusses the technical problems associated with the measurement and detection of microwaves for hazard protection and describes some of the instrumentation which is being used and developed for that purpose. The problems of measurement in the near field and the interpretation of near-field measurements are reviewed, and instrument design parameters necessary for unambiguous measurements are presented. Emphasis
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DIVISION OF ELECTRONIC PRODUCTS

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